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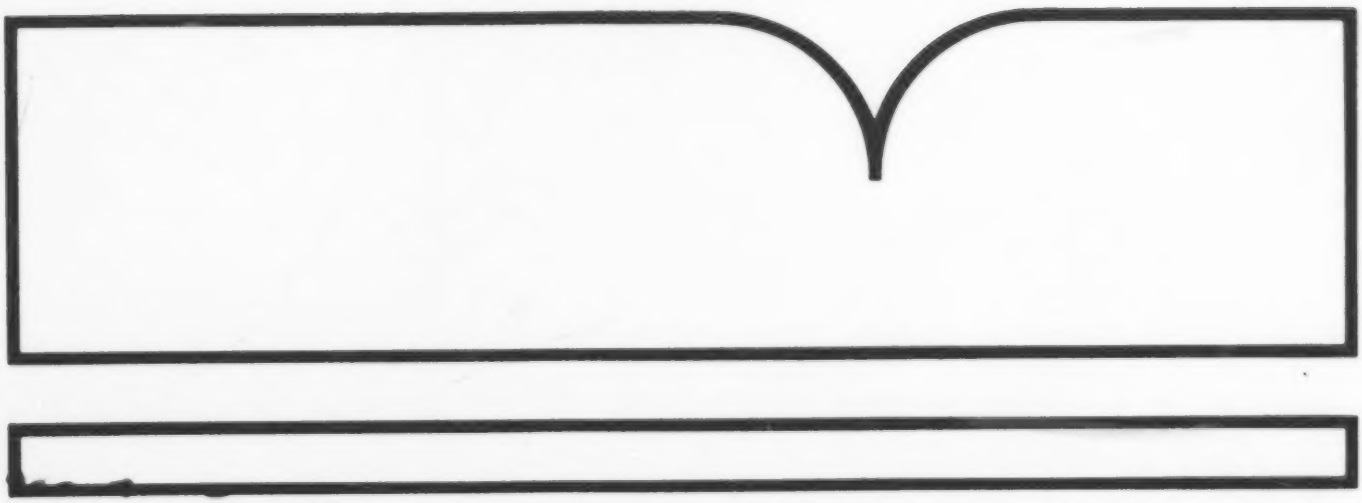

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16. ABSTRACT

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Analysis of National Water Pollution Control Policies
2. Agricultural Sediment Control

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Application of a national water network model permits an analysis of the likely affects of agricultural sediment control policies on the quality of the nation's waters. This analysis is believed superior to previous assessments based mainly on erosion estimates without accounting for the characteristics of the receiving water or the contribution of pollutants from nonagricultural activities. Specifically, while the earlier assessments concluded that agriculture-related pollution problems are widespread and ubiquitous, this analysis concludes that it is probably more efficient to focus sediment-related pollution control policies on about one third of the nation's agricultural regions.

INTRODUCTION

In a previous paper [*Gianessi et al.*, this issue] we described the RFF (Resources for the Future) National Water Network model, a large model for linking the residuals from industrial and agricultural activities to the quality of the nation's waters. This paper discusses a recent application of this model. Specifically, it was used to assist the U.S. Environmental Protection Agency and the U.S. Department of Agriculture to determine the extent to which it will be necessary to control pollution from agricultural sources in order to meet national water quality objectives.

BACKGROUND

Sediment and sediment-attached pollutants have long been recognized as the most widespread source of pollutants discharged into the nation's surface waters. However, Public Law 92-500, passed by Congress in 1972, placed its main emphasis on point source control. For example, by July 1, 1977, municipal sewage plants were required to install secondary treatment (ST), while industrial point sources were to install 'Best Practicable Control Technology Currently Available' (BPT). There is no provision in PL 92-500 for Federal regulation of nonpoint source pollution. However, Section 208 of the Act provides for Federal grants to local agencies to develop areawide plans for achieving water quality goals. Such plans would have to include adequate control of all sources of pollutants.

It has become apparent that U.S. water quality goals cannot be met for large areas of the country without reducing nonpoint discharges. [*U.S. Comptroller General*, 1977]. As the Council on Environmental Quality (CEQ) noted, '. . . water pollution from some conventional and toxic pollutants is still widespread. . . The primary reason is the impact of urban and agricultural runoff and other 'nonpoint' sources of pollution of water quality, a problem the nation has just begun to tackle.' [*U.S. Council on Environmental Quality*, 1979].

Yet fourteen states have already adopted sediment control statutes. For example, the state of Iowa requires soil conservation districts to set and implement agricultural soil loss limits, and complaints have been brought against individual farmers on the basis of their sediment damage. Future regulatory initiatives are likely to remain at the state level, since such land use controls have traditionally been considered the responsibility of state government. For a review of these laws, see *Holmes* [1979].

In addition, the U.S. Department of Agriculture (USDA) has long-standing soil and water conservation programs. These are important sources of technical and cost sharing assistance to farmers for controlling their pollution from runoff. The Soil and Conservation Service (SCS) assists in the development of resource inventories, the design of surveys, the design of conservation plans, and the development of cost data. They also provide on-site technical assistance. The Agricultural Stabilization and Conservation Service (ASCS) administers the Agriculture Conservation Program (ACP). This program allocates Federal money to states for cost-sharing assistance to farmers who request funds for conservation work. Since 1936, this program has resulted in the construction of 2.1 million miles (3.36 million km) of terraces to control runoff water and erosion [*U.S. Department of Agriculture, Agriculture Stabilization and Conservation Service*, 1979].

The Clean Water Act of 1977 established the Rural Clean Water Program (RCWP) under which the USDA, with the assistance of EPA, is to implement a program to develop Best Management Practices (BMPs) on agricultural land to control nonpoint source pollution. This act authorized $600 million for funds to be used to establish 5–10 year contracts with land owners in order to maintain the BMPs. [*Holmes*, 1979].

Because of the ubiquitous nature of agricultural nonpoint pollutant discharges, recent attempts to define the extent of the problem have led to a judgment that nearly all regions of the country are 'affected' by pollution from agricultural activities. [*U.S. Environmental Protection Agency*, 1978]. Furthermore, policy priorities were determined simply by looking at gross soil erosion with no allowance for the capacity of receiving waters to dilute sediment-related pollutants or for the fact that industrial and municipal sectors may be the dominating contributors. Only by modeling the complex interactions between the agricultural contribution, the contribution of other sectors, and the condition of receiving waters can the probable effects of sediment control policies be judged.

The RFF National Water Quality model simulations conducted for this project enable policy makers to identify more precisely those regions of the country where funding of cropland conservation programs may result in significantly improved water quality. Sediment control policies can be targeted to just those regions where such policies will serve water

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Fig. 1. The 105 producing areas [after *Wade and Heady*, 1976].

quality objectives. The gain in precision afforded by the model over less sophisticated or judgemental methods of identifying policy targets may lead to substantial savings in the costs of sediment control policies, both to the farmer and to the government.

METHOD

The basic approach was to supplement the county-by-county industrial pollutant inventories described in the previous paper [*Gianessi et al.*, 1981] with new county-by-county data on sediment loss and sediment-related pollutants from nonirrigated cropland, woodland, pastureland, and rangeland [*Gianessi et al.*, 1980]. These agriculture-related, nonpoint residuals were inserted into the water network at the appropriate geographical locations. The network model permitted simulations of water quality with and without these nonpoint residuals and under alternative assumptions of industrial and municipal point source control. Analysis of these simulations allowed for an assessment of the likely effectiveness of agriculture sediment controls on water quality in specific waterbodies nationwide.

USDA has estimated the annual amount of gross soil erosion that occurred in 1977 on nonirrigated cropland, woodland, rangeland, and pastureland for 105 producing areas (PAs). Figure 1 shows the location of these producing areas. Producing areas are conterminous with the 99 aggregated subareas (ASAs) of the Water Resources Council, with the exception of six ASAs which have been subdivided according to cropland characteristics. See *Wade and Heady* [1976] for a further description of the producing area concept. These estimates were made by applying the universal soil loss equation (USLE) to about 200,000 field sample points as part of USDA's 1977 National Resource Inventory (NRI). See *U.S. Department of Agriculture* [1980] for a description of the survey and *U.S. Department of Agriculture* [1978] for a full description of the USLE. The gross soil erosion estimates made

TABLE 1. Estimates of the National Discharge of Pollutants to Waterways by Sector

	5-Day Biochemical Oxygen Demand	Total Suspended Solids	Total Dissolved Solids	Total Phosphorus	Total Nitrogen
		Point Sources			
Industrial	8,252	50,355	290,184	353	559
Municipal	5,800	6,000	31,847	101	1,111
Total Point	14,052	56,355	322,031	454	1,670
		Nonpoint Sources			
Sediment					
Cropland	6,963	1,054,348	475,876	938	5,233
Woodland	1,742	214,141	121,961	259	1,068
Pastureland	1,133	173,430	72,161	147	752
Rangeland	3,855	932,695	380,249	1,191	3,185
Other*	3,449	1,027,525	440,368	420	2,202
		Other Nonpoint			
Urban	680	11,600	7,600	3	8
Other†	1,079	8,582	38,243	28	32
Total Nonpoint	18,901	3,422,321	1,536,458	2,986	12,480
National Total	32,953	3,478,676	1,858,489	3,440	14,150

All measurements in millions of pounds per year.

*Includes construction, mining, streambank erosion, and lake shoreline erosion.

†Includes irrigation return flow, acid mine drainage, oil spills, ballast discharges, discharges of watercraft sanitary wastes, ocean sludge dumping, vessel fuel loss, unsewered household discharge, and natural seepage.

TABLE 2. Distribution of Nodal Points Concentrations: Total Phosphorus

Concentration Range, mg/l	Number (and Percent) of Nodal Points by Concentration Range			
	Baseline 1972	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls
0.000–0.020	54 (5)	75 (7)	61 (6)	102 (10)
0.021–0.040	22 (2)	42 (4)	36 (3)	66 (6)
0.041–0.060	37 (3)	51 (5)	39 (4)	68 (6)
0.061–0.080	35 (3)	50 (5)	51 (5)	52 (5)
0.081–0.100	22 (2)	47 (4)	34 (3)	53 (5)
0.101–0.120	33 (3)	38 (4)	30 (3)	51 (5)
0.121–0.140	29 (3)	40 (4)	39 (4)	38 (4)
0.141–0.160	29 (3)	41 (4)	26 (2)	37 (3)
0.161–0.180	27 (3)	30 (3)	16 (2)	42 (4)
≥0.181	763 (73)	637 (60)	719 (68)	542 (52)
Total	1051 (100)	1051 (100)	1051 (100)	1051 (100)

by USDA includes only sheet and rill erosion. The annual soil loss per acre was computed and aggregations were made to the state and PA levels. The national gross soil erosion estimates total 1.706 billion metric tons for cropland, 0.284 billion metric tons for pastureland, 1.260 billion metric tons for rangeland, and 0.387 billion metric tons for woodland. Estimates of county gross soil erosion were then derived from the totals for PAs by ratioing county acreage estimates of woodland, pastureland, rangeland, and cropland in proportion to the county's share of the acreage of the PA.

Sediment delivery ratios (SDRs) were estimated for major land resource areas (MLRAs). SDRs measure that fraction of gross soil erosion which becomes sediment discharged to waterbodies. The procedure used to estimate these ratios has been recommended by the *U.S. Environmental Protection Agency* [1976] as well as by *Tubbs and Haith* [1980]. The procedure relies on a set of equations developed by the *Midwest Research Institute* [1975] (MRI). These equations estimate the sediment delivery ratio for a relatively homogeneous area as a function of the drainage density and the dominant soil texture for that area. Sediment delivery ratios are lower for coarse material and for areas far from the stream network. The MRI equations were used in conjunction with a set of estimates of drainage densities and soil texture developed for MLRAs. MLRAs are used as the geographic unit because the regions are defined according to the uniformity of relationships significant for agriculture [*U.S. Department of Agriculture*, 1972]. All counties within each MLRA were assumed to have the same sediment delivery ratios. The range of the SDRs across MLRAs is 71–95% for clay, 61–84% for silty clay, 55% for silt, 35–51% for loam, and 20–30% for sand.

Soil sediment contains organic and nutrient materials that are transported when sediment moves from fields into waterways. Estimates of average organic carbon and organic nitrogen content of soils in each MLRA were calculated from a data base drawn from SCS's 'Soil Survey Laboratory Data' for individual states [see *U.S. Department of Agriculture*, 1973]. Average values for MLRAs of total phosphorus in surface soil were derived from a USGS survey [*Schacklette*, 1971].

Several calculations were made to estimate ratios for pollutants attached to sediment. An enrichment factor of 2.0 was multiplied by the phosphorus, nitrogen, and carbon estimates to estimate the higher concentration expected in sediment in comparison to in situ soil [*Haith and Tubbs*, 1980]. A second calculation was the estimation of the 5-day biochemical oxygen demand (BOD_5) of the organic matter in the soil. The MRI assumption that BOD_5 concentration equals 0.1 times the soil organic matter content was adopted [*Midwest Research Institute*, 1977]. The final calculation was the conversion of 'sediment' discharge estimates into estimates of 'total suspended solids' and 'total dissolved solids.' Each MLRA was assigned to one of nine major river basins for which estimates of suspended and dissolved sediment ratios were available. The suspended fraction varies from 17% in the North Pacific region to 88% in the Colorado River region [see *Morisawa*, 1968].

All counties within each MLRA are assumed to have the

TABLE 3. Distribution of Nodal Points Concentrations: Total Kjeldahl Nitrogen

Concentration Range, mg/l	Number (and Percent) of Nodal Points by Concentration Range			
	Baseline 1972	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls
0.000–0.100	64 (6)	102 (10)	69 (7)	119 (11)
0.101–0.200	27 (3)	64 (6)	32 (3)	71 (7)
0.201–0.300	45 (4)	61 (6)	46 (5)	68 (6)
0.301–0.400	37 (4)	55 (5)	46 (5)	50 (5)
0.401–0.500	41 (4)	31 (3)	34 (3)	39 (4)
0.501–0.600	26 (2)	40 (4)	34 (3)	37 (3)
0.601–0.700	33 (3)	30 (3)	24 (2)	45 (4)
0.701–0.800	17 (2)	33 (3)	25 (2)	48 (5)
0.801–0.900	25 (2)	36 (3)	22 (2)	28 (3)
≥0.901	736 (70)	599 (57)	719 (68)	546 (52)
Total	1051 (100)	1051 (100)	1051 (100)	1051 (100)

TABLE 4. Distribution of Nodal Points Concentrations: 5-Day Biochemical Oxygen Demand

Concentration, Range, mg/l	Number (and Percent) of Nodal points by Concentration Range			
	Baseline 1972	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls
0.000–1.000	169 (16)	235 (22)	247 (23)	364 (35)
1.001–2.000	136 (13)	157 (15)	147 (14)	200 (19)
2.001–3.000	101 (10)	145 (14)	112 (10)	107 (10)
3.001–4.000	93 (9)	75 (7)	81 (8)	57 (5)
4.001–5.000	57 (5)	62 (6)	62 (6)	39 (4)
5.001–6.000	45 (4)	47 (4)	44 (4)	30 (3)
6.001–7.000	46 (4)	29 (3)	28 (3)	25 (2)
7.001–8.000	27 (3)	27 (3)	39 (4)	22 (2)
8.001–9.000	38 (4)	25 (2)	29 (3)	27 (3)
≥9.001	339 (32)	249 (24)	262 (25)	180 (17)
Total	1051 (100)	1051 (100)	1051 (100)	1051 (100)

same values for the ratios of sediment-attached pollutants. These ratios are also assumed to be the same for cropland, woodland, rangeland, and pastureland. Table 1 shows the discharge estimates for the national level aggregated by broad point and nonpoint source sector definitions.

POLICIES EXAMINED

Pollutant discharges were analyzed under four policy simulations and average seasonal flow conditions for summer, fall, winter, and spring. The four policies are:

1. Baseline 1972: This policy represents the quality of the water assuming no reduction in point source discharges from 1972 levels and no reduction in nonpoint sources.
2. Baseline 1972 with cropland controls: Point source discharges are held constant at 1972 levels while nonirrigated cropland discharges are reduced to zero. This policy represents the quality of the water after full cropland controls, assuming no point source reductions from 1972 levels.
3. After BPT/ST: Point source discharges are simulated after complete adoption of BPT and ST technologies. Nonpoint sources are not reduced. This policy simulates water quality improvements accomplished by point source controls only. Point sources of pollutants are very important during low flow conditions when nonpoint sources are not important [*Stamer et al.*, 1979]. Therefore, since average and not low flow conditions were simulated, these results do not provide for a complete evaluation of the effectiveness of the point source pollutant control program in reducing water quality violations.
4. After BPT/ST and cropland controls: Point source discharges are reduced to BPT/ST levels and nonirrigated cropland discharges are reduced to zero. This policy simulates the water quality improvements resulting from a combined point source and cropland control policy.

RESULTS

For presentation and analysis purposes, only concentration estimates for river nodal points under spring flow conditions are used. These estimates are summarized in Tables 2–5. As can be seen in Tables 2 and 3, the percentage of points in the worst quality class for total phosphorus (TP) and total Kjeldahl nitrogen (TKN) (≥0.181 mg/l for TP and ≥ 0.901 mg/l for TKN) is roughly 70% in the baseline 1972 simulation. This percentage falls to approximately 60% with adoption of cropland controls only. With point source BPT/ST controls only, the percentage of points in the worst case class is approximately 68%. A combination of cropland controls and point source BPT/ST controls reduces the number of points in the worst case class to 52%.

Table 4 summarizes the nodal point concentration estimates for BOD_5. As can be seen, the worst quality class interval (≥ 9.001 mg/l) includes approximately 32% of the points in the baseline 1972 simulation. This percentage falls to approximately 25% with either a point source or cropland control policy. In combination the two policies reduce this percentage to only 17% of the total number of points.

Table 5 shows the distribution of the nodal points' dissolved oxygen (DO) concentrations for the four policies. As can be seen, 83% of the points achieved a DO concentration in excess of 5.0 mg/l in the baseline simulation. This percentage rises to

TABLE 5. Distribution of Nodal Points Concentrations: Dissolved Oxygen

Concentration Range, mg/l	Number (and Percent) of Nodal Points by Concentration Range			
	Baseline 1972	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls
0.00–1.00	59 (6)	30 (3)	50 (5)	21 (2)
1.01–2.00	34 (3)	24 (2)	26 (2)	15 (2)
2.01–3.00	14 (1)	12 (1)	7 (1)	6 (1)
3.01–4.00	39 (4)	17 (2)	14 (1)	10 (1)
4.01–5.00	31 (3)	34 (3)	32 (3)	19 (2)
5.01–6.00	46 (4)	40 (4)	40 (4)	24 (2)
6.01–7.00	77 (7)	57 (5)	64 (6)	51 (5)
7.01–8.00	128 (12) (83)	114 (11) (89)	113 (11) (88)	100 (10) (92)
8.01–9.00	179 (17)	194 (18)	214 (20)	211 (20)
≥9.01	444 (43)	529 (51)	491 (47)	593 (55)
Total	1051 (100)	1051 (100)	1051 (100)	1051 (100)

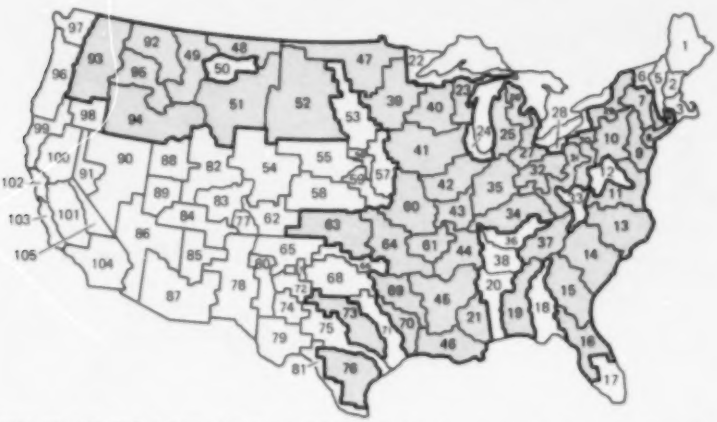

Fig. 2. Producing areas (shaded) where violations of the total phosphorus standard are reduced with a cropland sediment control policy.

approximately 88% with either a point or cropland control policy. Finally, a combination of the two policies results in 92% of the nodal points achieving a DO concentration in excess of 5 mg/l.

Results are also calculated in terms of the effect on water quality violations. The maps in Figures 2–5 summarize these estimates by policy option and by producing area for TP, TKN, BOD_5, and DO. Tables 6–9 show the percent reduction of violation under each policy option from the 1972 baseline condition. The violation standards used for these tables are 0.181 mg/l for TP, (Table 6), 0.901 mg/l for TKN (Table 7), 9.001 mg/l for BOD_5 (Table 8), and 5.0 mg/l for DO (Table 9).

For TP and TKN the model indicates that a cropland sediment control policy alone would reduce nodal point violations by 17 and 19%, respectively. A BPT/ST policy alone would reduce violations by 7 and 3%, respectively, while a combination of BPT/ST and cropland sediment control policy would reduce violations by 29 and 26%.

There are seven PAs for TP and eight for TKN where there are no nodal point violations in the baseline simulation and, of course, no violations under any of the subsequent policy options. Furthermore, there are 27 PAs where 100% of the points are in violation of the TP and TKN standards in the baseline simulation and remain in violation even after a combination of BPT/ST and cropland sediment control policies. Finally, there are 18 PAs for TP and 19 for TKN where the violation rate, while less than 100% in the baseline simulation, remains unchanged under the policy alternatives. Thus according to the model, control policy essentially would make no difference in water quality in 55 PAs for TP and 57 for TKN. On the other hand, there are 50 PAs for TP and 48 for TKN where a combination of BPT/ST and cropland sediment control policies will reduce the number of water quality violations. In seven PAs for TP and four for TKN, the violation reduction will be 100%.

For BOD_5 the model suggests that a cropland sediment control policy alone will reduce nodal point violations by 25%, while a BPT/ST policy alone would reduce violations by 22%. A combination BPT/ST and cropland sediment control policy would reduce violations by 47%.

There are 27 PAs where there are no violations of the BOD_5 standard in either the baseline simulation or under any of the subsequent control policies. In addition there are six PAs where 100% of the points are in violation of the BOD_5 standard in the baseline simulation and remain in violation even after a combination of BPT/ST and cropland sediment control policies. Finally, there are 21 PAs where the baseline vio-

Fig. 3. Producing areas (shaded) where violations of the total Kjeldahl nitrogen standard are reduced with a cropland sediment control policy.

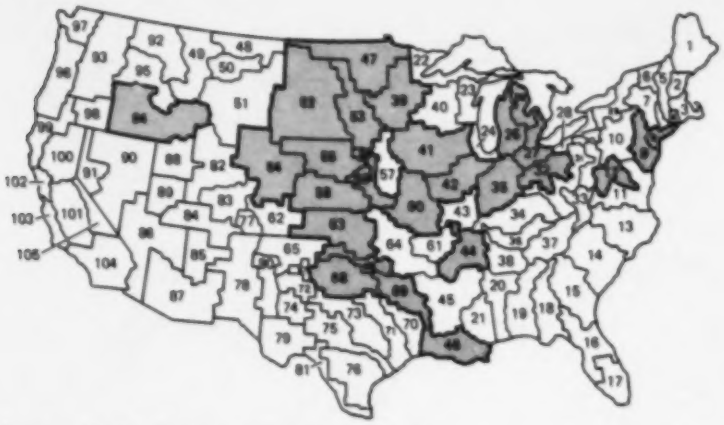

Fig. 4. Producing areas (shaded) where violations of the 5-day biochemical oxygen demand standard are reduced with a cropland sediment control policy.

lation rate is less than 100% and remains unchanged under the policy alternatives. Thus, according to the model, there are only 48 PAs where the combination of BPT/ST and cropland sediment control policies will reduce the number of BOD_5 violations, including 22 PAs where BOD_5 violations are completely alleviated.

For DO the model indicates that a cropland sediment control policy alone will reduce nodal point violations nationally by 35%, while a BPT/ST policy alone will reduce violations by 29%. A combination of the two policies will reduce violations by 59%. There are 40 PAs where there are no violations of the DO standard either in the baseline simulation or under any of the policy alternatives. In contrast to the situation with TP and TKN, there is only one PA where all the points are in violation of the DO standard in the baseline and remain in violation under the policy alternatives. Similar to the cases of the above pollutants, there are 16 PAs where the baseline violation rate is less than 100% and remains unchanged under the policy alternatives. Thus the analysis suggests that there are only 45 PAs where the combination of BPT/ST and cropland sediment control policies will reduce the number of DO violations, including 26 PAs where DO violations will be reduced by 100%.

Thus far, these results have been in terms of the impacts of a cropland sediment control policy measured from a baseline condition where BPT/ST are not fully implemented. In actual practice, however, a cropland sediment control policy may not be implemented until after the BPT/ST policy is fully adopted. In Table 10 we present the effectiveness of cropland sediment control policy in reducing violations of standards from an assumed fully implemented BPT/ST level. The estimated national reduction in violations are 31% for BOD_5, 24% for TKN, 25% for TP, and 44% for DO. The number of PAs where there is a reduction in violation of the standards totals 27 for BOD_5, 46 for TKN, 47 for TP, and 22 for DO.

In terms of nodal points the cropland sediment control policy will, according to the model, reduce violations at 82 points for BOD_5, 173 points for TKN, 177 points for TP, and 57 points for DO. However, because of overlaps among the separate pollutants, there are 307 separate nodal points where there will be an end of violations for one or more of the water quality parameters.

For some PAs a cropland sediment control policy alone will reduce pollutant violations. For example, all of the violations of the TP and TKN standard in PA 45 are apparently removed with a cropland control policy. Indeed, the BPT/ST

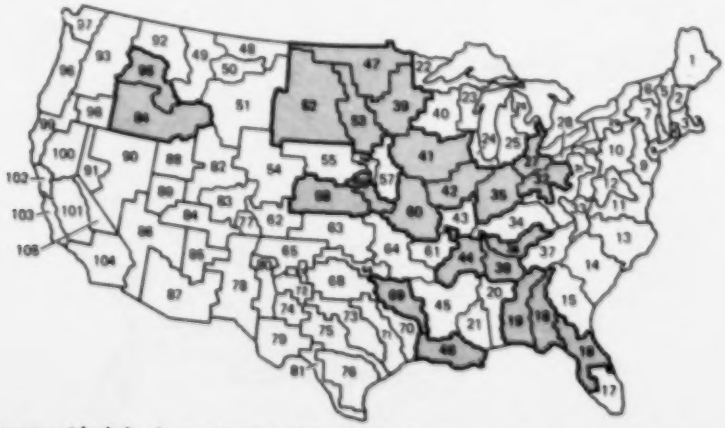

Fig. 5. Producing areas (shaded) where violations of the dissolved oxygen standard are reduced with a cropland sediment control policy.

policy does not reduce the violation rate at all in PA 45. This results from the dominance of the cropland pollutant discharges in this region.

In other PAs, however, the BPT/ST policy alone will reduce the violation rate completely without any need for controlling cropland discharges. This is particularly the case for BOD_5. In 10 PAs the model indicates that the BOD_5 violation rate drops to zero after a BPT/ST policy is adopted. In large part, this result is due to the relatively low loadings from cropland in these PAs.

The areas where a joint point and nonpoint source control policy will be advantageous can be identified by noting those instances where either the cropland policy or the BPT/ST policy alone makes a partial reduction in the violation rate while the combination of the two policies results in a substantial reduction. In PA 15, for example, a cropland control policy is shown to reduce the TKN violation rate by 35% and a BPT/ST policy, by 17%. A combination of the two policies is estimated to reduce the violation rate by 83%. There are numerous nodal points where the incremental amount removed by one policy or the other makes the difference from a water quality standpoint.

Finally, attention needs to be drawn to the Pacific Coast and the Southwest, where no PAs are identified in Table 10 as benefiting from a cropland sediment control policy for any of the pollutants. (Also, see Figures 2–5.) This situation results from a combination of the factors discussed above. For example, there are PAs where there are no violations of water quality standards to begin with, such as PA 97 (Puget Sound). There are PAs where there will be continued violations of water quality standards even after the adoption of cropland sediment controls due to the overwhelming dominance of other discharging sectors. For example, there is no apparent reduction of water quality violations in PA 85 (the Little Colorado) with a cropland sediment control policy. The discharge of pollutants from rangeland, pastureland, and woodland in this PA overwhelms the discharge from cropland: 1300 times the cropland loading for BOD_5, 1500 times for TP, and 1700 times for TKN. One other consideration in analyzing the results for the Southwest is that the streamflow at most nodal points is extremely small: in many instances it is below 100 $ft^3/5$. For this reason, even relatively small discharges from any sector point, nonpoint, or even natural streambank erosion may result in violations of water quality standards.

Calibration and Verification of Baseline Results

It is quite common for water modelers to calibrate their models. Generally such calibration means that the values of one or more of the model's paramenters are adjusted such that the model exactly agrees with a base set of monitored data. We have not followed such a procedure for two reasons.

First, it is not clear how one would go about doing such a calibration with a model as large and complex as the RFF Water Network Model. If the model fails to fit the base data exactly, one could choose to adjust various physical parameters such as decay rates, average velocities, widths, etc., or one could adjust assumptions regarding the amount of pollution discharged from various industrial activities, their locations, their assignments to network nodes, etc. Even though there may be as many as two or three hundred monitored data values to calibrate with, there are many more parameters that could be adjusted. In other words, the degrees of freedom are simply too large to make calibration a practical possibility. The large number of degrees of freedom would also make sensitivity testing an endless exercise.

Secondly, it is not clear that even if calibration were possible, it would be meaningful for a policy model. Suppose there were an equality between data points and parameters such that the degrees of freedom were zero. Such a model could then be exactly calibrated, but it might be, at worst, a very silly model or, at best, a sensible model but useless for policy analysis. Thus one could estimate BOD concentration at a nodal point as a fixed proportion of the population of counties associated with that nodal point. It would be very easy to calibrate such a model and, indeed, it may predict BOD quite well. However, such a model would be useless for the type of policy analyses discussed in this paper. Thus the value of calibrating a model must be assessed in terms of what the model is to be used for.

Of course, none of the analyses reported herein is of much value if the estimated pollution concentrations are highly inaccurate. Although there are no standard measures of accuracy for these sorts of estimates, we can get a qualitative 'feel' for the performance of the model by comparing baseline 1972 concentration estimates with recorded observations taken in approximately the same period of time. Fortunately, about 10% of the network's nodes correspond to official monitoring stations where actual measurements are made for the pollutants estimated in the system. However, before examining this comparison, the following points concerning verification need to be made:

1. The model is not designed to replicate the 'real world' exactly. Indeed, no model can. Rather, the model is meant to highlight 'problem' areas, areas where additional in-depth regional study and planning are necessary. While the model's estimates for these problem areas may vary from actual monitored data, the model will have performed its task satisfactorily if it accurately predicts problem areas relative to other 'cleaner' areas. The exact concentration estimates are not crucial to this task. The model is intended for national level planning and evaluation purposes. A key question in 'verifying' such a model is: What policy conclusions are drawn from this model and how would they compare to policies drawn either from other available national models or from judgment? We note that the model's results are consistent with the latest national water quality assessment done by the Council on Environmental Quality (CEQ). We reported that the model's baseline result for TP had 70% of the nodal points in the worst quality class, while 83% of the nodal points' DO concentration results were greater than the standard of 5.0 mg/l. The latest CEQ report's analysis of national water quality data concluded that '. . . violation rates for DO were generally low in most areas . . .' and . . . 'High violation rates [for total phosphorus] exist across the country' [*U.S. Council on Environmental Quality*, 1979]. Thus the model's conclusions for these pollutants are consistent with the CEQ's.

2. How 'accurate' the model is should not be determined solely from comparison with ambient data. Rather, the model's performance should be compared to the performance of other models or judgmental procedures. We are aware that there are individual river and lake models that supposedly predict ambient concentrations within a claimed 25% 'error' in relation to monitoring data. However, as noted above, it is common to calibrate these models to a set of monitoring data

TABLE 6. Effectiveness of BPT/ST and Cropland Sediment Control Policies in Reducing Violations of the Total Phosphorus Standard from Baseline Level

Producing Area	Total number of nodal points	Percentage of Nodal Points in Violation				Percent Reduction of Nodal Point Violations From Baseline 1972 Conditions		
		Baseline 1972	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls
1	17	0	0	0	0	*a*	*a*	*a*
2	7	0	0	0	0	*a*	*a*	*a*
3	2	50	50	50	50	0	0	0
4	5	40	20	40	20	50	0	50
5	9	0	0	0	0	*a*	*a*	*a*
6	0							
7	7	86	57	86	57	33	0	33
8	7	100	71	100	57	29	*b*	43
9	13	100	92	100	69	8	*b*	31
10	14	86	14	86	14	84	0	84
11	9	89	78	89	56	12	0	37
12	8	100	100	100	100	*b*	*b*	*b*
13	19	63	53	32	16	16	49	75
14	21	48	33	10	0	31	79	100
15	26	31	27	12	4	13	61	87
16	16	25	6	25	6	76	0	76
17	4	75	75	75	75	0	0	0
18	19	26	26	11	11	0	58	58
19	23	35	13	22	0	63	37	100
20	10	10	10	10	10	0	0	0
21	13	38	31	38	15	18	0	61
22	4	0	0	0	0	*a*	*a*	*a*
23	7	29	14	29	0	51	0	100
24	0							
25	11	82	36	82	36	56	0	56
26	8	100	88	50	0	12	50	100
27	14	71	29	71	21	59	0	70
28	4	50	50	50	50	0	0	0
29	9	56	11	56	0	80	0	100
30	12	83	83	83	75	0	0	10
31	28	100	89	100	82	11	*b*	18
32	15	100	93	100	93	7	*b*	7
33	10	100	100	100	100	*b*	*b*	*b*
34	14	100	79	100	79	21	*b*	21
35	18	100	94	100	78	6	*b*	22
36	6	33	33	33	33	0	0	0
37	15	60	60	60	47	0	0	22
38	5	0	0	0	0	*a*	*a*	*a*
39	7	100	71	100	43	29	*b*	57
40	14	100	36	79	21	64	21	79
41	26	100	50	100	38	50	*b*	62
42	17	100	65	100	24	35	*b*	76
43	7	100	71	100	0	29	*b*	100
44	11	100	82	82	45	18	18	55
45	11	36	0	36	0	100	0	100
46	12	50	25	50	25	50	0	50
47	12	75	33	75	25	56	0	67
48	3	100	67	100	67	33	*b*	33
49	12	100	92	100	92	8	*b*	8
50	3	100	100	100	100	*b*	*b*	*b*
51	18	89	83	89	83	7	0	7
52	19	84	74	84	74	12	0	12
53	17	94	94	94	94	0	0	0
54	13	100	100	100	100	*b*	*b*	*b*
55	12	100	100	100	100	*b*	*b*	*b*
56	2	100	100	100	100	*b*	*b*	*b*
57	3	100	100	100	100	*b*	*b*	*b*
58	13	100	100	100	100	*b*	*b*	*b*
59	5	100	100	100	100	*b*	*b*	*b*
60	21	90	86	90	86	4	0	4
61	12	75	50	67	50	33	11	33
62	4	100	100	100	100	*b*	*b*	*b*
63	17	100	94	100	94	6	0	6
64	14	57	57	57	50	0	0	12
65	6	100	100	100	100	*b*	*b*	*b*

TABLE 6. (continued)

Producing Area	Total number of nodal points	Percentage of Nodal Points in Violation				Percent Reduction of Nodal Point Violations From Baseline 1972 Conditions		
		Baseline 1972	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls
66	10	100	100	100	100	[b]	[b]	[b]
67	8	100	100	100	100	[b]	[b]	[b]
68	7	100	100	100	100	[b]	[b]	[b]
69	22	45	27	45	23	40	0	49
70	9	56	56	11	11	0	80	80
71	6	67	67	67	67	0	0	0
72	8	100	100	100	100	[b]	[b]	[b]
73	8	88	88	75	50	0	15	43
74	10	80	80	80	80	0	0	0
75	8	62	62	62	62	0	0	0
76	11	100	91	100	91	9	[b]	9
77	1	100	100	100	100	[b]	[b]	[b]
78	6	83	83	83	83	0	0	0
79	9	100	100	100	100	[b]	[b]	[b]
80	5	60	60	60	60	0	0	0
81	7	100	100	100	100	[b]	[b]	[b]
82	3	100	100	100	100	[b]	[b]	[b]
83	8	100	100	100	100	[b]	[b]	[b]
84	5	100	100	100	100	[b]	[b]	[b]
85	3	33	33	33	33	0	0	0
86	9	78	78	78	78	0	0	0
87	10	50	50	50	50	0	0	0
88	6	100	100	100	100	[b]	[b]	[b]
89	3	100	100	100	100	[b]	[b]	[b]
90	3	100	100	100	100	[b]	[b]	[b]
91	5	100	100	100	100	[b]	[b]	[b]
92	15	47	47	40	33	0	15	30
93	16	50	38	44	38	24	12	24
94	15	100	80	100	47	20	[b]	53
95	12	58	33	50	17	43	14	71
96	17	18	18	18	18	0	0	0
97	4	0	0	0	0	[a]	[a]	[a]
98	0							
99	6	83	83	83	83	0	0	0
100	9	100	100	100	100	[b]	[b]	[b]
101	15	100	100	93	93	[b]	7	7
102	2	100	100	100	100	[b]	[b]	[b]
103	4	75	75	75	75	0	0	0
104	3	67	67	67	67	0	0	0
105	0							
106[c]	3	0	0	0	0	[a]	[a]	[a]
Number, national total	1051	763	637	719	542	126	44	221
Percentage, national total	(100)	(73)	(61)	(68)	(52)	(17)	(7)	(29)

[a] No points in violation in baseline 1972 condition.
[b] 100% of the points in violation in baseline 1972 condition and after policy adoption.
[c] Alaska

for some base period. It is not surprising that these models compare well with monitoring data for periods not too far removed from the base period.

3. Finally, we note that the model is a first attempt at national water quality modeling. There are simply no reasonably similar competitors. In view of the fact that the only realistic alternative for national policy assessment is the application of 'judgment', we believe that the verification results reported below can only be regarded as very promising.

The model's estimates of TP and TKN concentrations for 158 nodal points can be compared directly to ambient concentration measurements made in 1975 at USGS NASQAN stations located at exactly the same point. NASQAN is a uniform national stream monitoring network maintained by USGS. It consists of a total of 445 stations. 1975 is the year closest to 1972 for which published data are available for all NASQAN stations. NASQAN sampling is designed so that [*Briggs and Ficke*, 1977]

> . . . The samples provide a fairly good representation of what one would expect to find in the stream on any given day. They do not, however, necessarily provide good information on . . . the complete range of concentrations because the samples usually are not collected during the periods of highest flows or extremes in concentration.

For 1975 there were approximately 12 measurements made of TP and TKN at each of the 158 NASQAN stations included in this comparison.

TABLE 7. Effectiveness of BPT/ST and Cropland Sediment Control Policies in Reducing Violations of the Total Kjeldahl Nitrogen Standard from Baseline Levels

Producing Area	Total Number of Nodal Points	Percentage of Nodal Points in Violation				Percent Reduction of Nodal Point Violations From Baseline 1972 Conditions		
		Baseline 1972	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls
1	17	0	0	0	0	a	a	a
2	7	0	0	0	0	a	a	a
3	2	0	0	0	0	a	a	a
4	5	40	0	20	0	100	50	100
5	9	0	0	0	0	a	a	a
6	0							
7	7	86	43	86	43	50	0	50
8	7	71	71	71	71	0	0	0
9	13	100	69	100	62	31	b	32
10	14	100	14	93	14	86	7	86
11	9	67	56	67	22	16	0	67
12	8	100	100	100	100	b	b	b
13	19	63	37	58	21	41	8	67
14	21	43	10	24	5	77	44	88
15	26	23	15	19	4	35	17	83
16	16	25	6	25	6	76	0	76
17	4	75	75	50	50	0	33	33
18	19	26	26	21	16	0	19	38
19	23	17	4	9	4	76	47	76
20	10	30	10	30	10	33	0	33
21	13	46	31	46	15	33	0	67
22	4	25	25	25	25	0	0	0
23	7	71	14	71	14	80	0	80
24	0							
25	11	100	82	100	64	18	b	36
26	8	75	62	75	12	17	0	84
27	14	71	29	71	21	59	0	70
28	4	50	50	50	50	0	0	0
29	9	56	11	56	0	80	0	100
30	12	83	75	83	50	10	0	40
31	28	100	89	93	86	11	7	14
32	15	100	93	100	93	7	0	7
33	10	100	100	100	100	b	b	b
34	14	79	50	79	50	37	0	37
35	18	100	83	100	78	17	b	22
36	6	33	33	33	17	0	0	48
37	15	60	60	60	60	0	0	0
38	5	0	0	0	0	a	a	a
39	7	100	86	100	14	14	b	86
40	14	100	50	100	50	50	b	50
41	26	100	69	100	38	31	b	62
42	17	100	76	100	47	24	b	53
43	7	71	29	71	0	59	0	100
44	11	73	64	73	45	12	0	38
45	11	64	0	64	0	100	0	100
46	12	50	8	50	8	84	0	84
47	12	75	42	75	42	44	0	44
48	3	100	67	100	67	33	b	33
49	12	100	92	100	92	8	b	8
50	3	100	100	100	100	b	b	b
51	18	89	89	89	89	0	0	0
52	19	89	79	89	79	11	0	11
53	17	94	88	94	88	6	0	6
54	13	100	100	100	100	b	b	b
55	12	100	100	100	100	b	b	b
56	2	100	100	100	100	b	b	b
57	3	100	100	100	100	b	b	b
58	13	100	100	100	100	b	b	b
59	5	100	100	100	100	b	b	b
60	21	90	86	90	86	4	0	4
61	12	75	50	75	50	33	0	33
62	4	100	100	100	100	b	b	b
63	17	100	100	100	94	b	b	6
64	14	57	50	50	43	12	12	25

TABLE 7. (Continued)

Producing Area	Total Number of Nodal Points	Percentage of Nodal Points in Violation				Percent Reduction of Nodal Point Violations From Baseline 1972 Conditions		
		Baseline 1972	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls
65	6	100	100	100	100	*b*	*b*	*b*
66	10	100	100	100	100	*b*	*b*	*b*
67	8	100	100	100	100	*b*	*b*	*b*
68	7	100	100	100	100	*b*	*b*	*b*
69	22	41	18	41	18	56	0	56
70	9	56	56	44	22	0	21	61
71	6	67	67	67	67	0	0	0
72	8	100	100	100	100	*b*	*b*	*b*
73	8	88	75	75	75	15	15	15
74	10	80	80	80	80	0	0	0
75	8	88	75	88	62	15	0	30
76	11	100	100	100	100	*b*	*b*	*b*
77	1	100	100	100	100	*b*	*b*	*b*
78	6	83	83	83	83	0	0	0
79	9	100	100	100	100	*b*	*b*	*b*
80	5	60	60	60	60	0	0	0
81	7	100	100	100	100	*b*	*b*	*b*
82	3	100	100	100	100	*b*	*b*	*b*
83	8	100	100	100	100	*b*	*b*	*b*
84	5	100	100	100	100	*b*	*b*	*b*
85	3	33	33	33	33	0	0	0
86	9	78	78	78	78	0	0	0
87	10	50	50	50	50	0	0	0
88	6	100	100	100	100	*b*	*b*	*b*
89	3	100	100	100	100	*b*	*b*	*b*
90	3	100	100	100	100	*b*	*b*	*b*
91	5	100	100	100	100	*b*	*b*	*b*
92	15	40	40	40	40	0	0	0
93	16	31	25	31	25	19	0	19
94	15	67	40	67	40	40	0	40
95	12	0	0	0	0	*a*	*a*	*a*
96	17	12	12	12	12	0	0	0
97	4	0	0	0	0	*a*	*a*	*a*
98	0							
99	6	67	67	67	67	0	0	0
100	9	89	89	89	89	0	0	0
101	15	93	93	93	93	0	0	0
102	2	100	100	100	100	*b*	*b*	*b*
103	4	75	75	75	75	0	0	0
104	3	67	67	67	67	0	0	0
105	0							
106[c]	3	0	0	0	0	*a*	*a*	*a*
Number, national total	1051	736	599	719	546	137	17	190
Percentage, national total	(100)	(70)	(57)	(68)	(52)	(19)	(3)	(26)

[a] No points in violation in baseline 1972 condition.
[b] 100% of the points in violation in baseline 1972 condition and after policy adoption.
[c] Alaska.

For 96 of the nodal points, EPA's Office of Water Planning and Standards prepared an extract of DO ambient concentration measurements for the summers of 1971–1972 from their STORET data system. About 5–7 measurements were made for each station over the two summers.

These data permit an analysis of how many cases the RFF modeled values fall within the range of observed values. It also permits an analysis of how many instances the RFF model 'correctly' classifies a nodal point as 'clean' or 'polluted' according to some benchmark standard. Table 11 summarizes the RFF, NASQAN, and STORET data for this purpose. As can be seen, the model's estimates fall within the range of observed values in 44–49% of the cases. In terms of classifying a point correctly as polluted or not polluted (i.e., whether the concentration is above a standard or not) the model agrees with the monitoring data in 72–76% of the cases.

Thus far this verification attempt has considered monitoring data to be correct and has judged the accuracy of the model in terms of how well it agrees with these correct observations. However, monitoring information is subject to wide variations in accuracy for at least three reasons.

The first of these reasons is insufficient sampling frequency.

TABLE 8. Effectiveness of BPT/ST and Cropland Sediment Control Policies in Reducing Violations of the 5-Day Biochemical Oxygen Demand Standard from Baseline Levels

Producing Area	Total Number of Nodal Points	Percentage of Nodal Points in Violation				Percent Reduction of Nodal Point Violations From Baseline 1972 Conditions		
		Baseline 1972	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls
1	17	0	0	0	0	*a*	*a*	*a*
2	7	0	0	0	0	*a*	*a*	*a*
3	2	0	0	0	0	*a*	*a*	*a*
4	5	0	0	0	0	*a*	*a*	*a*
5	9	0	0	0	0	*a*	*a*	*a*
6	0							
7	7	0	0	0	0	*a*	*a*	*a*
8	7	43	43	29	0	0	33	100
9	13	23	23	15	8	0	35	65
10	14	0	0	0	0	*a*	*a*	*a*
11	9	0	0	0	0	*a*	*a*	*a*
12	8	38	38	25	0	0	34	100
13	19	16	11	5	5	31	69	69
14	21	24	10	0	0	58	100	100
15	26	12	8	0	0	25	100	100
16	16	6	6	0	0	0	100	100
17	4	50	50	0	0	0	100	100
18	19	5	0	0	0	100	100	100
19	23	0	0	0	0	*a*	*a*	*a*
20	10	10	10	0	0	0	100	100
21	13	15	8	0	0	47	100	100
22	4	0	0	0	0	*a*	*a*	*a*
23	7	0	0	0	0	*a*	*a*	*a*
24	0							
25	11	18	0	9	0	100	50	100
26	8	25	0	12	0	100	52	100
27	14	29	21	14	7	28	52	76
28	4	50	50	25	25	0	50	50
29	9	0	0	0	0	*a*	*a*	*a*
30	12	0	0	0	0	*a*	*a*	*a*
31	28	18	14	7	7	22	61	61
32	15	40	0	7	0	100	82	100
33	10	0	0	0	0	*a*	*a*	*a*
34	14	0	0	0	0	*a*	*a*	*a*
35	18	44	17	33	0	61	25	100
36	6	0	0	0	0	*a*	*a*	*a*
37	15	20	20	0	0	0	100	100
38	5	0	0	0	0	*a*	*a*	*a*
39	7	43	0	43	0	100	0	100
40	14	7	7	7	7	0	0	0
41	26	62	12	54	4	81	13	94
42	17	53	18	47	6	66	11	89
43	7	0	0	0	0	*a*	*a*	*a*
44	11	18	9	18	0	50	0	100
45	11	0	0	0	0	*a*	*a*	*a*
46	12	17	17	17	0	0	0	100
47	12	75	0	75	0	100	0	100
48	3	0	0	0	0	*a*	*a*	*a*
49	12	42	42	42	42	0	0	0
50	3	100	100	100	100	*b*	*b*	*b*
51	18	22	22	22	22	0	0	0
52	19	79	63	79	63	20	0	20
53	17	88	53	82	47	40	7	47
54	13	77	69	77	62	10	0	19
55	12	75	42	75	33	44	0	56
56	2	100	0	100	0	100	*b*	100
57	3	0	0	0	0	*a*	*a*	*a*
58	13	100	77	92	77	23	8	23
59	5	40	40	40	40	0	0	0
60	21	38	14	38	14	63	0	63
61	12	8	8	8	8	0	0	0
62	4	75	75	75	75	0	0	0
63	17	76	71	59	53	7	22	30
64	14	21	21	7	7	0	91	91
65	6	100	100	100	100	*b*	*b*	*b*

TABLE 8. (continued)

Producing Area	Total Number of Nodal Points	Percentage of Nodal Points in Violation				Percent Reduction of Nodal Point Violations From Baseline 1972 Conditions		
		Baseline 1972	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls
66	10	70	60	40	30	14	43	37
67	8	100	100	100	100	*b*	*b*	*b*
68	7	86	71	43	29	17	50	66
69	22	18	18	5	0	0	72	100
70	9	44	44	11	11	0	75	75
71	6	33	33	33	33	0	0	0
72	8	75	75	75	75	0	0	0
73	8	50	38	25	25	24	50	50
74	10	70	70	70	70	0	0	0
75	8	38	25	25	25	34	34	34
76	11	45	36	27	27	20	40	40
77	1	100	100	100	100	*b*	*b*	*b*
78	6	83	83	67	67	0	19	19
79	9	89	89	89	89	0	0	0
80	5	60	60	60	60	0	0	0
81	7	14	0	0	0	100	100	100
82	3	67	67	67	67	0	0	0
83	8	50	38	25	25	24	50	50
84	5	60	60	60	60	0	0	0
85	3	33	33	33	33	0	0	0
86	9	56	56	56	56	0	0	0
87	10	50	50	50	50	0	0	0
88	6	50	50	50	50	0	0	0
89	3	100	100	100	100	*b*	*b*	*b*
90	3	100	100	100	100	*b*	*b*	*b*
91	5	40	40	40	40	0	0	0
92	15	7	7	7	7	0	0	0
93	16	0	0	0	0	*a*	*a*	*a*
94	15	27	13	27	13	52	0	52
95	12	0	0	0	0	*a*	*a*	*a*
96	17	0	0	0	0	*a*	*a*	*a*
97	4	0	0	0	0	*a*	*a*	*a*
98	0							
99	6	0	0	0	0	*a*	*a*	*a*
100	9	22	22	11	11	0	50	50
101	15	47	47	13	13	0	72	72
102	2	100	100	0	0	*b*	100	100
103	4	75	75	75	75	0	0	0
104	3	67	67	67	67	0	0	0
105	0							
106[c]	3	0	0	0	0	*a*	*a*	*a*
Number, national total	1051	339	249	262	180	90	77	159
Percentage, national total	(100)	(32)	(24)	(25)	(17)	(25)	(22)	(47)

[a]No points in violation in baseline 1972 condition.
[b]100% of the points in violation in baseline 1972 condition and after policy adoption.
[c]Alaska.

Measurements of DO at a river point from continuous measuring devices often vary 50% over a 24-hour period. [*U.S. Geological Survey*, 1973]. Monthly variations for a point are also subject to the same (if not greater) wide range. Thus the use of just six measurements of DO over a 3-month period cannot be expected to detect the full range of actual DO conditions at a river point. Furthermore, the NASQAN measurements of TKN and TP are explicitly collected on 'typical' days. Therefore USGS cautions that they do not represent the full range of concentrations found in the river. For these reasons, unless there is far more frequent sampling, it will be impossible for monitoring data to provide an authoritative report on the full range of actual pollutant concentrations.

The second reason is measurement inaccuracy due to the chemical process of the test employed to determine the concentration. For example, the standard test used for BOD analysis does not exactly reproduce the biophysical characteristics of rivers. As a result the oxidation rate in rivers may be quite different than the laboratory rate. As *Morrissette and Mavinic* [1978] have stated

> . . . (1) the turbulence found in streams is not reproduced in the standard BOD test; (2) the temperature of the stream may differ from the 20° test procedure; (3) the amount of sunlight received in the stream is not reproduced in the dark incubators; and (4) the oxygen concentration of the BOD bottle differs from that of the stream, since the latter is usually continually replenished.

TABLE 9. Effectiveness of BPT/ST and Cropland Sediment Control Policies in Reducing Violations of the Dissolved Oxygen Standard from Baseline Levels

Producing Area	Total Number of Nodal Points	Percentage of Nodal Points in Violation				Percent Reduction of Nodal Point Violations From Baseline 1972 Conditions		
		Baseline 1972	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls
1	17	0	0	0	0	*a*	*a*	*a*
2	7	0	0	0	0	*a*	*a*	*a*
3	2	0	0	0	0	*a*	*a*	*a*
4	5	0	0	0	0	*a*	*a*	*a*
5	9	0	0	0	0	*a*	*a*	*a*
6	0							
7	7	0	0	0	0	*a*	*a*	*a*
8	7	0	0	0	0	*a*	*a*	*a*
9	13	15	15	0	0	0	100	100
10	14	0	0	0	0	*a*	*a*	*a*
11	9	0	0	0	0	*a*	*a*	*a*
12	8	38	38	25	25	0	35	35
13	19	0	0	0	0	*a*	*a*	*a*
14	21	5	5	0	0	0	100	100
15	26	4	4	0	0	0	100	100
16	16	25	12	12	0	50	50	100
17	4	25	25	0	0	0	100	100
18	19	26	11	11	5	58	58	81
19	23	17	13	13	0	24	24	100
20	10	50	50	40	40	0	20	20
21	13	0	0	0	0	*a*	*a*	*a*
22	4	0	0	0	0	*a*	*a*	*a*
23	7	0	0	0	0	*a*	*a*	*a*
24	0							
25	11	0	0	0	0	*a*	*a*	*a*
26	8	0	0	0	0	*a*	*a*	*a*
27	14	7	7	7	0	0	0	100
28	4	0	0	0	0	*a*	*a*	*a*
29	9	0	0	0	0	*a*	*a*	*a*
30	12	33	33	17	17	0	49	49
31	28	0	0	0	0	*a*	*a*	*a*
32	15	13	0	13	0	100	0	100
33	10	10	10	0	0	0	100	100
34	14	0	0	0	0	*a*	*a*	*a*
35	18	28	5	22	0	83	22	100
36	6	17	0	17	0	100	0	100
37	15	7	7	7	7	0	0	0
38	5	40	20	20	0	50	50	100
39	7	71	0	71	0	100	0	100
40	14	7	7	7	7	0	0	0
41	26	35	8	35	8	78	0	78
42	17	47	11	29	6	77	39	88
43	7	14	0	0	0	100	100	100
44	11	27	9	27	9	67	0	67
45	11	0	0	0	0	*a*	*a*	*a*
46	12	33	17	33	17	49	0	49
47	12	25	0	25	0	100	0	100
48	3	0	0	0	0	*a*	*a*	*a*
49	12	0	0	0	0	*a*	*a*	*a*
50	3	0	0	0	0	*a*	*a*	*a*
51	18	11	11	11	11	0	0	0
52	19	32	21	32	21	35	0	35
53	17	59	24	59	24	60	0	60
54	13	15	8	0	0	50	100	100
55	12	8	8	8	8	0	0	0
56	2	0	0	0	0	*a*	*a*	*a*
57	3	0	0	0	0	*a*	*a*	*a*
58	13	38	30	8	0	22	79	100
59	5	20	0	20	0	100	0	100
60	21	29	0	29	0	100	0	100
61	12	25	25	25	25	0	0	0
62	4	25	25	25	25	0	0	0
63	17	0	0	0	0	*a*	*a*	*a*
64	14	7	7	7	7	0	0	0

TABLE 9. (continued)

Producing Area	Total Number of Nodal Points	Percentage of Nodal Points In Violation				Percent Reduction of Nodal Point Violations From Baseline 1972 Conditions		
		Baseline 1972	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls	After Cropland Controls	After BPT/ST	After BPT/ST and Cropland Controls
65	6	0	0	0	0	[a]	[a]	[a]
66	10	10	10	0	0	0	100	100
67	8	12	0	0	0	100	100	100
68	7	29	29	14	14	0	52	52
69	22	14	14	5	0	0	65	100
70	9	22	22	11	11	0	50	50
71	6	50	50	17	17	0	66	66
72	8	12	12	12	12	0	0	0
73	8	25	25	12	12	0	50	50
74	10	30	30	20	20	0	33	33
75	8	0	0	0	0	[a]	[a]	[a]
76	11	55	55	55	55	0	0	0
77	1	0	0	0	0	[a]	[a]	[a]
78	6	0	0	0	0	[a]	[a]	[a]
79	9	44	44	44	44	0	0	0
80	5	20	20	20	20	0	0	0
81	7	14	14	14	14	0	0	0
82	3	0	0	0	0	[a]	[a]	[a]
83	8	0	0	0	0	[a]	[a]	[a]
84	5	0	0	0	0	[a]	[a]	[a]
85	3	100	100	100	100	[b]	[b]	[b]
86	9	22	22	22	22	0	0	0
87	10	80	80	80	80	0	0	0
88	6	33	33	17	17	0	50	50
89	3	33	33	33	33	0	0	0
90	3	67	67	67	67	0	0	0
91	5	0	0	0	0	[a]	[a]	[a]
92	15	0	0	0	0	[a]	[a]	[a]
93	16	0	0	0	0	[a]	[a]	[a]
94	15	13	7	13	7	50	0	50
95	12	8	0	8	0	100	0	100
96	17	0	0	0	0	[a]	[a]	[a]
97	4	0	0	0	0	[a]	[a]	[a]
98	0							
99	6	0	0	0	0	[a]	[a]	[a]
100	9	22	22	11	11	0	50	50
101	15	13	13	0	0	0	100	100
102	2	100	100	0	0	[b]	100	100
103	4	50	50	0	0	0	100	100
104	3	100	100	33	33	[b]	67	67
105	0							
106[c]	3	0	0	0	0	[a]	[a]	[a]
Number, national total	1051	177	117	129	72	60	48	105
Percentage, national total	(100)	(17)	(11)	(12)	(7)	(35)	(29)	(59)

[a] No points in violation in baseline 1972 conditions.
[b] 100% of the points in violation in baseline 1972 conditions and after policy adoption.
[c] Alaska.

The imprecision of laboratory tests can be further illustrated by noting the different results one obtains, depending on the method used in the analysis. One recent study discovered that TKN and TP measurements from manually depth integrated samples were 28% and 18% lower than samples obtained from fixed point automated samplers [*Bliven*, 1979].

Finally, field and laboratory procedures can introduce inaccuracy into the resulting monitored information. If a sample is not preserved properly or analyzed promptly, test results are meaningless. [*U.S. Environmental Protection Agency*, 1975]. If fresh chemicals are not used or if laboratory equipment is not calibrated properly, the test results cannot be relied on. Data from different laboratories often are significantly different in analysis of split samples from the same river point [*American Chemical Society*, 1978]. Indifferent and poorly trained personnel also can contribute to unreliable measurements.

It is thus not possible to determine authoritatively the water quality of the nation's rivers from the available monitoring data. More importantly, because we must always take cognizance of the purpose of the model, one cannot assess the model's predictions simply because there is a lack of agreement with monitoring information.

TABLE 10. Effectiveness of Cropland Sediment Control Policy in Reducing Violations of Standards from BPT/ST Levels

Producing Area	Number of Nodal Points Where Violations Cease				As Percent of Violated Points at BPT/ST Level			
	BOD_5	TKN	TP	DO	BOD_5	TKN	TP	DO
1	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
2	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
3	*a*	*a*	0	*a*	*a*	*a*	0	*a*
4	*a*	1	1	*a*	*a*	100	50	*a*
5	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
6								
7	*a*	3	2	*a*	*a*	50	33	*a*
8	2	0	3	*a*	100	0	57	*a*
9	1	5	4	*a*	50	38	69	*a*
10	*a*	11	10	*a*	*a*	85	83	*a*
11	*a*	4	3	*a*	*a*	67	38	*a*
12	2	*b*	*b*	0	100	*b*	*b*	0
13	0	7	3	*a*	0	64	50	*a*
14	*a*	4	2	*a*	*a*	80	100	*a*
15	*a*	4	2	*a*	*a*	80	67	*a*
16	*a*	3	3	2	*a*	75	75	100
17	*a*	0	0	*a*	*a*	0	0	*a*
18	*a*	1	0	1	*a*	25	0	50
19	*a*	1	5	3	*a*	50	100	100
20	*a*	2	0	0	*a*	67	0	0
21	*a*	4	3	*a*	*a*	67	60	*a*
22	*a*	0	*a*	*a*	*a*	0	*a*	*a*
23	*a*	4	2	*a*	*a*	80	100	*a*
24								
25	1	4	5	*a*	100	36	56	*a*
26	1	5	4	*a*	100	83	100	*a*
27	1	7	7	1	50	70	70	100
28	0	0	0	*a*	0	0	0	*a*
29	*a*	5	5	*a*	*a*	100	100	*a*
30	*a*	4	1	0	*a*	40	10	0
31	0	2	5	*a*	0	8	18	*a*
32	1	1	1	2	100	7	7	100
33	*a*	*b*	*b*	*a*	*a*	*b*	*b*	*a*
34	*a*	4	3	*a*	*a*	36	21	*a*
35	6	4	4	4	100	22	22	100
36	*a*	1	0	1	*a*	50	0	100
37	*a*	*b*	2	0	*a*	*b*	22	0
38	*a*	*a*	*a*	1	*a*	*a*	*a*	100
39	3	6	4	5	100	86	57	100
40	0	7	8	0	0	50	73	0
41	13	11	16	7	93	42	62	78
42	7	9	13	4	88	47	76	80
43	*a*	5	7	*a*	*a*	100	100	*a*
44	2	3	4	2	100	38	44	67
45	*a*	7	4	*a*	*a*	100	100	*a*
46	2	5	3	2	100	83	50	50
47	9	5	6	3	100	56	67	100
48	*a*	1	1	*a*	*a*	33	33	*a*
49	0	1	1	*a*	0	8	8	*a*
50	*b*	*b*	*b*	*a*	*b*	*b*	*b*	*a*
51	0	0	1	0	0	0	6	0
52	3	2	2	2	20	12	12	33
53	6	1	0	6	43	6	0	60
54	2	*b*	*b*	*a*	20	*b*	*b*	*a*
55	5	*b*	*b*	0	44	*b*	*b*	0
56	2	*b*	*b*	*a*	100	*b*	*b*	*a*
57	*a*	*b*	*b*	*a*	*a*	*b*	*b*	*a*
58	2	*b*	*b*	1	17	*b*	*b*	100
59	0	*b*	*b*	1	37	*b*	*b*	100
60	5	1	1	6	62	5	5	100
61	0	2	2	0	0	25	25	0
62	0	*b*	*b*	0	0	*b*	*b*	0
63	1	1	1	*a*	10	6	6	*a*
64	0	1	1	0	0	14	12	0
65	*b*	*b*	*b*	*a*	*b*	*b*	*b*	*a*
66	1	*b*	*b*	*a*	25	*b*	*b*	*a*
67	*b*	*b*	*b*	*a*	*b*	*b*	*b*	*a*
68	1	*b*	*b*	0	33	*b*	*b*	0
69	1	5	5	1	100	56	50	100
70	0	2	0	0	0	50	0	0
71	0	0	0	0	0	0	0	0

TABLE 10. (continued)

Producing Area	Number of Nodal Points Where Violations Cease				As Percent of Violated Points at BPT/ST Level			
	BOD_5	TKN	TP	DO	BOD_5	TKN	TP	DO
72	0	*b*	*b*	0	0	*b*	*b*	0
73	0	0	2	0	0	0	33	0
74	0	0	0	0	0	0	0	0
75	0	2	0	*a*	0	29	0	*a*
76	0	*b*	1	0	0	*b*	9	0
77	*b*	*b*	*b*	*a*	*b*	*b*	*b*	*a*
78	0	0	0	*a*	0	0	0	*a*
79	0	*b*	*b*	0	0	*b*	*b*	0
80	0	0	0	0	0	0	0	0
81	*a*	*b*	*b*	0	*a*	*b*	*b*	0
82	0	*b*	*b*	*a*	0	*b*	*b*	*a*
83	0	*b*	*b*	*a*	0	*b*	*b*	*a*
84	0	*b*	*b*	*a*	0	*b*	*b*	*a*
85	0	0	0	*b*	0	0	0	*b*
86	0	0	0	0	0	0	0	0
87	0	0	0	0	0	0	0	0
88	0	*b*	*b*	0	0	*b*	*b*	0
89	*b*	*b*	*b*	0	*b*	*b*	*b*	0
90	*b*	*b*	*b*	0	*b*	*b*	*b*	0
91	0	*b*	*b*	*a*	0	*b*	*b*	*a*
92	0	0	1	*a*	0	0	17	*a*
93	*a*	1	1	*a*	*a*	20	14	*a*
94	2	4	8	1	50	40	53	50
95	*a*	*a*	4	1	*a*	*a*	67	100
96	*a*	0	0	*a*	*a*	0	0	*a*
97	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
98								
99	*a*	0	0	*a*	*a*	0	0	*a*
100	0	0	*b*	0	0	0	*b*	0
101	0	0	0	*a*	0	0	0	*a*
102	*a*	*b*	*b*	*a*	*a*	*b*	*b*	*a*
103	0	0	0	*a*	0	0	0	*a*
104	0	0	0	0	0	0	0	0
105								
106[c]	*a*	*a*	*a*	0	*a*	*a*	*a*	*a*
Total	82	173	177	57	31	24	25	44

[a]No points in violation after BPT/ST.
[b]All points in the PA in violation after BPT/ST and also after BPT/ST plus cropland controls.
[c]Alaska.

LIMITATIONS OF THE ANALYSIS

Three types of limitations are discussed below: data limitations, water quality network design limitations, and policy analysis limitations.

Data Limitations

One obvious limitation in the data used for this analysis is that the data are a combination of point source data for 1972 and nonpoint source data for 1977. As a result the baseline simulation does not refer to any actual year. Currently, the point source inventories are being updated to 1977, allowing a uniform data base for future research.

A second problem is that the assignment of point and nonpoint pollutant discharge by polluting sector to counties often depends upon crude techniques. For example, average values are frequently assumed to apply in all locations. The actual discharges in any particular county could be far from 'average.'

A third problem concerns the estimates of sediment that actually reaches bodies of water. These estimates rely on a set of procedures that have been criticized by USDA as likely to result in substantial overstatement of the amount of sediment reaching waterways [*Boyce*, 1979]. Finally, the data base upon which the cropland gross soil erosion estimates are based (the 1977 National Resource Inventory) excludes erosion from snowmelt and Federal lands.

Water Quality Network Model Design Limitations

The most important limitation is that the network model includes only a small fraction of the actual number of bodies of water in the United States. Many thousands of small streams, lakes, estuaries, and other bodies of water are excluded from the network. These smaller bodies of water may play an extremely important role in the transport and decay of pollutants. For example, many off-stream reservoirs act as 'sediment traps' that remove enormous amounts of sediment from reaching the major waterbodies [*Dendy and Champion*, 1978]. Preliminary investigation has begun of the possibility of delineating the model according to the much more detailed REACH file maintained by EPA's Office of Water Planning and Standards. However, the basic problem with increasing the number of modeled nodal points is the difficulty of acquiring data for even the small list of hydrodynamic parameters included in the model: width and velocity of flow, for example.

Almost as important, in view of the model's application to agricultural sediment problems, is that the model currently does not include estimates of the transport and deposition of suspended solids. Suspended solids are probably the single most important pollutant associated with cropland sediment loss, but the transport processes governing this pollutant and the effects of lessening the discharge of solids into bodies of

TABLE 11. Summary of Comparison of Modeled TP, TKN, and DO Concentration Estimates With Monitored Data

	TKN	TP	DO
Total number of points	158	158	96
Number of points where ranges overlap	69	69	47
Percentage	(44)	(44)	(49)
Number of points where classification is the same			
Violation	60	85	4
No Violation	53	35	69
Total	113	120	73
Percentage	(72)	(76)	(76)

water are not well understood. It is likely, however, that the bodies of water identified in this report as benefiting from reduced water quality violations for BOD_5, TP, and TKN would be the ones to benefit from a reduced load of suspended solids as well.

A third problem related to the suspended sediment transport issue is the current model representation of the transport and decay of sediment-attached pollutants (such as TP, TKN, and BOD_5). Since suspended sediment deposition is not accounted for, these pollutants are transported in the system as if they were independent of the sediment. However, some portion of these pollutants remain attached to the sediment. This problem may not be as serious as it first seems. Those bodies of water (such as large reservoirs) that, according to the model, reduce these pollutants significantly, would likely be the same bodies of water that would cause significant reductions in suspended solids.

A final limitation of the model is the very simple, linear form of the transport equations. They obviously are not as sophisticated as some of the three-dimensional equations developed in some studies. However, the data demands and cost of applying such equations to the entire country currently prohibit their use in national policy analysis.

Policy Analysis Limitations

It should be clear that this paper has not considered all of the water quality impacts of cropland sediment loss. In addition to not explicitly accounting for water quality effects of suspended solids, the model also does not consider the water quality impacts of herbicides and pesticides that may be attached to sediment.

Phosphorus and nitrogen pollutants from cropland also reach bodies of water dissolved in overland runoff unattached to sediment. Pollutants from this source are not accounted for in the results reported herein. However, an effort was made to estimate for all regions of the country by crop the amounts of phosphorus and nitrogen that reach waterways in this form. The Cornell Nutrient Simulation Model [*Tubbs and Haith*, 1980] was used for this purpose. The results indicate that, nationally, overland runoff accounts for 0.08 times the sediment load sources for nitrogen and 0.01 times for phosphorus. Although these are relatively small shares of the sediment loads, they may be more important from a water quality viewpoint since such dissolved nutrients are generally 'available' for aquatic plant growth, whereas the nutrients attached to sediment may not be as available [*Schuman et al.*, 1973]. In future runs of the model the transport and decay of these two nutrient forms will be explicitly accounted for, separately.

The policies analyzed in this study are fairly simple. Mixed policy strategies have not been analyzed except for the mixture of 100% BPT and cropland sediment control. A variety of policies might lead to a more efficient solution to the problem of degraded water quality. For example, funds from the Rural Clean Water Program (RCWP) could be used to reduce loadings from rangeland and pastureland. A number of reasonable mixed policy simulations could be analyzed in future research.

For analyzing the water quality impacts of cropland sediment control a 100% reduction in cropland sediment discharge is simulated. This scenario may overstate the water quality improvements for practices likely to be adopted in the various regions. In other regions, however, some fraction of sediment removal less than 100% may be adequate to achieve the water quality improvements. The policy analysis was focused solely on river points. For nutrients the effects on lakes may be more critical and of more interest.

Finally, this research effort was not directed toward identifying the most appropriate cropland controls for each region of the country. Uniform national control policies have been simulated. We are not recommending the adoption of any uniform policy. Linear programing models such as those used by Iowa State University [*Wade and Heady*, 1976] and Cornell University [*Robillard and Bruckner*, 1979] can be used for identifying the specific practice appropriate for a given region.

CONCLUSIONS

This paper has identified those rivers and regions of the country where cropland sediment controls may result in significantly improved water quality. The baseline simulations indicate widespread violations of nitrogen (TKN) and phosphorus (TP) water quality standards. Violations of 5-day biochemical oxygen demand (BOD_5) and dissolved oxygen (DO) standards are significantly lower. These results are in agreement with the latest water quality monitoring data available for the nation.

The paper shows the results of three policy simulations: a point source control policy (BPT/ST), a cropland sediment control policy, and full implementation of the first two policies. The simulations indicate that the first two policies by themselves would result in varying degrees of water quality improvement nationally. However, full implementation of these two policies would result in significantly improved water quality in many regions of the country. The paper shows that such a policy would further reduce water quality violations over that which could be expected by point source controls along by the following percentages: 31% for BOD_5, 24% for TKN, 25% for TP, and 44% for DO. In all, the model estimates that approximately one third of the nation's river points will experience significantly improved water quality with the adoption of the cropland sediment control policy in addition to the point source control policy.

However, even after full implementation of point source and sediment control policies, approximately one half of the nation's rivers will still experience violations of the TP and TKN standards. This analysis suggests that attention will have to be given to reducing other nonpoint sources of these pollutants, such as pastureland, rangeland, and urban runoff.

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